Research Article

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Novel soliton solutions to the Atangana–Baleanu fractional system of equations for the ISALWs

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Abstract: This work deals the construction of novel soliton solutions to the Atangana–Baleanu (AB) fractional system of equations for the ion sound and Langmuir waves by using Sardar-subequation method (SSM). The outcomes are in the form of bright, singular, dark and combo soliton solutions. These solutions have wide applications in the arena of optoelectronics and wave propagation. The bright solitons will be a vast advantage in controlling the soliton disorder, dark solitons are also beneficial for soliton communication when a background wave exists and singular solitons only elaborate the shape of solitons and show a total spectrum of soliton solutions created from the model. These results would be very helpful to study and understand the physical phenomena in nonlinear optics. The performance of the SSM shows that this is powerful, talented, suitable and direct technique to discover the exact solutions for a number of nonlinear fractional models.

Keywords: Sardar-subequaion method, system of ISALWs with AB fractional derivative, soliton solutions

1 Introduction

Recently, the exploration of novel results of nonlinear fractional differential equations (NLFDEs) has become much interested for many researchers in different fields of physical sciences. The analysis of such models plays a significant role to understand the everyday physical phenomena in nonlinear evolution equations. These models may have great impact in many fields of science as well as plasma physics, fluid dynamics, optical fibers, solid-state physics and biology. Therefore, it has become a very hot issue to search wave solutions for such type of equations for well understanding of their internal structures. Many analytical and numerical approaches have been developed to discover wave solutions such as homogenous balance method [1], Kudryashov's method [2], tanh method [3], modified extended tanh-function method [4], sine-cosine method [5], extended and improved F-expansion method [6], Backlund transformation method [7,8], inverse scattering method [9], truncated Painleve expansion method [10], variational method [11], asymptotic method [12], Hirota's bilinear method [13–17], homotopy perturbation method [18], method of integrability [19], soliton perturbation theory [20], generalized Darboux transformation method [21], He's semi-inverse variational method [22], variational the sine-Gordon expansion (SGE) method [23], new extended direct algebraic method [24–26], modified EDAM [27], mapping method [28], generalized Riccati equation mapping method and (G'/G)-expansion method [29], sine-Gordon method and Kudryashov method [30], modified Kudryashov method [31,32], generalized auxiliary equation method [33], Jacobi elliptic function method [34], q-homotopy analysis method [35], kernel Hilbert space method [36], reproducing kernel method [37–39] and Laplace transform method [40]. The target of this work is discovering some novel soliton solutions for a system of ion sound and Langmuir waves (ISALWs) with AB fractional-order derivative by using Sardar-subequation method (SSM) [41].

This article is structured as follows: Section 2 contains the governing model. SSM is described in Section 3. Section 4 consists of optical solitons solutions of system of equations for ISALWs with AB fractional derivative using SSM. Section 5 contains results and discussion, while conclusion of this work is written in Section 6.

2 Governing model

A system of ISALWs with AB fractional-order derivative defined for $\alpha = 1$ [42] is given as

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$$\begin{aligned} &{}_{t}^{\mathrm{ABR}}\mathrm{D}_{0^+}^{\alpha} + E + \frac{1}{2}\frac{\partial^2 E}{\partial y^2} - nE = 0,\ \ t > 0,\ \ 0 < \alpha \le 1,\\ &{}_{t}^{\mathrm{ABR}}\mathrm{D}_{0^+}^{\alpha} + n - \frac{\partial^2 n}{\partial y^2} - 2\frac{\partial^2(|E|^2)}{\partial y^2} = 0, \end{aligned} \tag{1}$$

where n and $Ee^{-\iota w_p t}$ are the perturbation using normalized density and the normalized electric field, respectively, connected with the Langmuir waves [42]. The variables y and t are normalized and the AB fractional operator is ${}_{t}^{\mathrm{ABR}}\mathrm{D}\alpha_{0^+}^{\alpha}$ with order $\alpha \in (0, 1)$ in direction t, then the AB fractional derivative is defined as [43,44]

$$ {}_{t}^{\mathrm{ABR}}\mathrm{D}_{0^+}^{\alpha} f(t) = \frac{\varpi(\alpha)}{1-\alpha}\frac{\mathrm{d}}{\mathrm{d}t}\int_0^{\alpha} f(x)\Xi_{\alpha}\left(\frac{-\alpha(t-\alpha)^{\alpha}}{1-\alpha}\right), \tag{2}$$

where $\Xi_\alpha(.)$ is the Mittag–Leffler function, taken as

$$\Xi_{\alpha}\left(\frac{-\alpha(t-\alpha)^{\alpha}}{1-\alpha}\right) = \sum_{s=0}^{\infty}\frac{\left(\frac{-\alpha}{1-\alpha}\right)^{s}(t-y)^{\alpha s}}{\Gamma(\alpha s+1)} \tag{3}$$

and $\varpi(\alpha)$ is a normalization function. Then, the AB fractional operator for $f(t)$ converts

$$ {}_{t}^{\mathrm{ABR}}\mathrm{D}_{a^+}^{\alpha} f(t) = \frac{\varpi(\alpha)}{1-\alpha}\sum_{s=0}^{\infty}\left(\frac{-\alpha}{1-\alpha}\right)^{s} {}^{\mathrm{RL}}\mathrm{I}_{a}^{\alpha s} f(t). \tag{4}$$

The Langmuir waves arise as coherent field structures with peak intensities beyond the Langmuir downfall thresholds. Their scale sizes are of the order of the wavelength of an ion sound wave. These Langmuir waves physically show the short wavelength ion sound waves which are created during the thermalization of the burnt-out cavitons left behind by the Langmuir collapse. Likewise, the highest intensities of the experiential short wavelength ion sound waves are comparable to the predictable intensities of those ion sound waves emitted by the burnt-out cavitons.

3 The SSM

Let the fractional partial differential equation

$$H\left({}_{t}^{\mathrm{ABR}}\mathrm{D}_{0^+}^{\alpha} p, \frac{\partial p}{\partial x}, {}_{t}^{\mathrm{ABR}}\mathrm{D}_{0^+}^{2\alpha} p, \frac{\partial^2 p}{\partial x^2}, \ldots\right) = 0, \quad t > 0,\ \ 0 < \alpha \le 1, \tag{5}$$

where H is an unknown function [41]. Using the following transformation to (5)

$$p(x,t) = p(\zeta),\ \ \zeta = x + \frac{k(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}, \quad k \neq 0. \tag{6}$$

Using (6) into (5), which converts to non-linear ODE as

$$Q(p, p', p'', \ldots) = 0, \tag{7}$$

assume that (7) takes the solution as

$$p(\zeta) = \sum_{j=0}^{S} B_i \Phi^i(\zeta), \tag{8}$$

where $B_i (0 \le j \le S)$ are constants to be determined later. $\Phi(\zeta)$ simplifies the non-linear ODE as follows:

$$(\Phi'(\zeta))^2 = \varepsilon + c\Phi^2(\zeta) + \Phi^4(\zeta), \tag{9}$$

where c and ε are constants and (9) admits the solution as

Case 1: When $c > 0$ and $\varepsilon = 0$, then

$$\Phi_1^{\pm}(\zeta) = \pm\sqrt{-cpq}\,\mathrm{sech}_{pq}(\sqrt{c}\,\zeta),$$
$$\Phi_2^{\pm}(\zeta) = \pm\sqrt{cpq}\,\mathrm{csch}_{pq}(\sqrt{c}\,\zeta),$$

where

$$\mathrm{sech}_{pq}(\zeta) = \frac{2}{pe^{\zeta} + qe^{-\zeta}},\ \ \mathrm{csch}_{pq}(\zeta) = \frac{2}{pe^{\zeta} - qe^{-\zeta}}.$$

Case 2: When $c < 0$ and $\varepsilon = 0$, then

$$\Phi_3^{\pm}(\zeta) = \pm\sqrt{-cpq}\,\sec_{pq}(\sqrt{-c}\,\zeta),$$
$$\Phi_4^{\pm}(\zeta) = \pm\sqrt{-cpq}\,\csc_{pq}(\sqrt{-c}\,\zeta),$$

where

$$\sec_{pq}(\zeta) = \frac{2}{pe^{\iota\zeta} + qe^{-\iota\zeta}},\ \ \csc_{pq}(\zeta) = \frac{2\iota}{pe^{\iota\zeta} - qe^{-\iota\zeta}}.$$

Case 3: When $c < 0$ and $\varepsilon = \frac{c^2}{4b}$, then

$$\Phi_5^{\pm}(\zeta) = \pm\sqrt{-\frac{c}{2}}\tanh_{pq}\left(\sqrt{-\frac{c}{2}}\,\zeta\right),$$
$$\Phi_6^{\pm}(\zeta) = \pm\sqrt{-\frac{c}{2}}\coth_{pq}\left(\sqrt{-\frac{c}{2}}\,\zeta\right),$$
$$\Phi_7^{\pm}(\zeta) = \pm\sqrt{-\frac{c}{2}}(\tanh_{pq}(\sqrt{-2c}\,\zeta) \pm \iota\sqrt{pq}\,\mathrm{sech}_{pq}(\sqrt{-2c}\,\zeta)),$$
$$\Phi_8^{\pm}(\zeta) = \pm\sqrt{-\frac{c}{2}}(\coth_{pq}(\sqrt{-2c}\,\zeta) \pm \sqrt{pq}\,\mathrm{csch}_{pq}(\sqrt{-2c}\,\zeta)),$$
$$\Phi_9^{\pm}(\zeta) = \pm\sqrt{-\frac{c}{8}}\left(\tanh_{pq}\left(\sqrt{-\frac{c}{8}}\,\zeta\right) + \coth_{pq}\left(\sqrt{-\frac{c}{8}}\,\zeta\right)\right),$$

where

$$\tanh_{pq}(\zeta) = \frac{pe^{\zeta} - qe^{-\zeta}}{pe^{\zeta} + qe^{-\zeta}},\ \ \coth_{pq}(\zeta) = \frac{pe^{\zeta} + qe^{-\zeta}}{pe^{\zeta} - qe^{-\zeta}}.$$

Case 4: When $c > 0$ and $\varepsilon = \frac{c^2}{4}$, then

$$\Phi_{10}^{\pm}(\zeta) = \pm\sqrt{\frac{c}{2}}\tan_{pq}\left(\sqrt{\frac{c}{2}}\zeta\right),$$

$$\Phi_{11}^{\pm}(\zeta) = \pm\sqrt{\frac{c}{2}}\cot_{pq}\left(\sqrt{\frac{c}{2}}\zeta\right),$$

$$\Phi_{12}^{\pm}(\zeta) = \pm\sqrt{\frac{c}{2}}(\tan_{pq}(\sqrt{2c}\zeta) \pm \sqrt{pq}\sec_{pq}(\sqrt{2c}\zeta)),$$

$$\Phi_{13}^{\pm}(\zeta) = \pm\sqrt{\frac{c}{2}}(\cot_{pq}(\sqrt{2c}\zeta) \pm \sqrt{pq}\csc_{pq}(\sqrt{2c}\zeta)),$$

$$\Phi_{14}^{\pm}(\zeta) = \pm\sqrt{\frac{c}{8}}\left(\tan_{pq}\left(\sqrt{\frac{c}{8}}\zeta\right) + \cot_{pq}\left(\sqrt{\frac{c}{8}}\zeta\right)\right),$$

where

$$\tan_{pq}(\zeta) = -\iota\frac{pe^{\iota\zeta} - qe^{-\iota\zeta}}{pe^{\iota\zeta} + qe^{-\iota\zeta}},\quad \cot_{pq}(\zeta) = \iota\frac{pe^{\iota\zeta} + qe^{-\iota\zeta}}{pe^{\iota\zeta} - qe^{-\iota\xi}}.$$

3.1 Mathematical analysis

This section deals the capability of the proposed scheme for solving (1), assuming that

$$\begin{aligned} E(x,t) &= p(\zeta)e^{\iota\mu},\quad n(x,t) = v(\zeta),\\ \mu &= kx + \frac{\delta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)},\\ \zeta &= \gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}, \end{aligned}\tag{10}$$

where δ and τ are constants. Then, by putting (10) into (1) we obtain the following:

$$\frac{1}{2}\gamma^2 p'' + \iota(\tau + k\gamma)p' - 0.5(k^2 + 2\delta)p - vp = 0,\tag{11}$$

$$(\tau^2 - \gamma^2)v'' + 4\gamma^2(p'^2 - pp'') = 0.\tag{12}$$

On splitting (12) into imaginary and real parts as follows:

$$\beta - k\gamma,\tag{13}$$

and integrating twice (12) with respect to ζ, we obtain

$$v = \frac{2\gamma^2}{\tau^2 - \gamma^2}p^2 = \frac{2}{k^2 - 1}p^2,\tag{14}$$

Inserting (13) and (14) into (11), finally results in

$$p'' - \frac{4}{\gamma^2(k^2 - 1)}p^3 - \frac{k^2 + 2\delta}{\gamma^2}p = 0\tag{15}$$

or

$$p'' = \frac{k^2 + 2\delta}{\gamma^2}p - \frac{4}{\gamma^2(k^2 - 1)}p^3 = 0.\tag{16}$$

3.2 Application of the SSM

Here, SSM is utilized for the solutions of (16). Using balancing method in terms of p'' and p^3 in (16), we obtain $S = 1$, so (8) converts to

$$p(\zeta) = B_0 + B_1\Phi(\zeta),\tag{17}$$

where B_0 and B_1 are constant terms to be calculated. Finally, inserting (17) into (16) by the fact that (9) is admitted to adjust all coefficients of $\Phi^i(\zeta)$ to zero, we reach a class of algebraic systems, on solving it, and obtain

$$B_0 = 0,\quad B_1 = \frac{\sqrt{-1 + k^2}\gamma}{\sqrt{2}},\qquad \delta = \frac{1}{2}(-k^2 + c\gamma^2).\tag{18}$$

Case 1: When $c > 0$ and $\varepsilon = 0$, then

$$E_{1,1}^{\pm}(x,t) = \frac{\sqrt{-1 + k^2}\gamma}{\sqrt{2}}\left(\pm\sqrt{-pqc}\,\mathrm{sech}_{pq}\left(\sqrt{c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right) \times e^{\iota\left(kx + \frac{\delta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},\tag{19}$$

$$n_{1,1}^{\pm}(x,t) = \frac{\sqrt{-1 + k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-pqc}\,\mathrm{sech}_{pq}\left(\sqrt{c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right),\tag{20}$$

$$E_{1,2}^{\pm}(x,t) = \frac{\sqrt{-1 + k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{pqc}\,\mathrm{csch}_{pq}\left(\sqrt{c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-r}}{B(\alpha)\sum_{r=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{r}\Gamma(1-\alpha r)}\right)\right)\right) \times e^{\iota\left(kx + \frac{\delta(1-\alpha)t^{-r}}{B(\alpha)\sum_{r=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{r}\Gamma(1-\alpha r)}\right)},\tag{21}$$

$$n_{1,2}^{\pm}(x,t) = \frac{\sqrt{-1 + k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{pqc}\,\mathrm{csch}_{pq}\left(\sqrt{c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right).\tag{22}$$

Case 2: When $c < 0$ and $\varepsilon = 0$, then

$$E_{1,3}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-pqc}\,\sec_{pq}\left(\sqrt{-c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha r)}\right)\right)\right) \times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)}, \tag{23}$$

$$n_{1,3}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-pqc}\,\sec_{pq}\left(\sqrt{-c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right), \tag{24}$$

$$E_{1,4}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-pqc}\,\csc_{pq}\left(\sqrt{-c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{r=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right) \times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)}, \tag{25}$$

$$n_{1,4}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-pqc}\,\csc_{pq}\left(\sqrt{-c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right). \tag{26}$$

Case 3: When $a < 0$ and $\varepsilon = \frac{a^2}{4b}$, then

$$E_{1,5}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-\frac{c}{2}}\tanh_{pq}\left(\sqrt{-\frac{c}{2}}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right) \times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)}, \tag{27}$$

$$n_{1,5}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-\frac{c}{2}}\tanh_{pq}\left(\sqrt{-\frac{c}{2}}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right), \tag{28}$$

$$E_{1,6}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-\frac{c}{2}}\coth_{pq}\left(\sqrt{-\frac{c}{2}}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right) \times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)}, \tag{29}$$

$$n_{1,6}^{\pm}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-\frac{c}{2}}\coth_{pq}\left(\sqrt{-\frac{c}{2}}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right), \tag{30}$$

$$\begin{aligned} E_{1,7}^{\pm}(x,t) = {} & \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-\frac{c}{2}}\left(\tanh_{pq}\left(\sqrt{-2c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right)\right)\right) \\ & \pm \iota\sqrt{pq}\,\mathrm{sech}_{pq}\left(\sqrt{-2c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right) \times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)}, \end{aligned} \tag{31}$$

$$\begin{aligned} n_{1,7}^{\pm}(x,t) = {} & \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \left(\pm\sqrt{-\frac{c}{2}}\left(\tanh_{pq}\left(\sqrt{-2c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha r)}\right)\right)\right)\right) \\ & \pm \iota\sqrt{pq}\,\mathrm{sech}_{pq}\left(\sqrt{-2c}\left(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^s\Gamma(1-\alpha s)}\right)\right), \end{aligned} \tag{32}$$

$$E^{\pm}_{1,8}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\times\left(\pm\sqrt{-\frac{c}{2}}\left(\coth_{pq}\left(\sqrt{-2c}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right)\right.$$
$$\left.\pm\sqrt{pq}\,\mathrm{csch}_{pq}\left(\sqrt{-2c}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right)\times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},\tag{33}$$

$$n^{\pm}_{1,8}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\left(\pm\sqrt{-\frac{c}{2}}\left(\coth_{pq}\left(\sqrt{-2c}\left(\gamma x+\frac{\beta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right)\right.$$
$$\left.\pm\sqrt{pq}\,\mathrm{csch}_{pq}\left(\sqrt{-2c}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right),\tag{34}$$

$$E^{\pm}_{1,9}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\times\left(\pm\sqrt{-\frac{c}{8}}\left(\tanh_{pq}\left(\sqrt{-\frac{c}{8}}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right.\right.$$
$$\left.\left.+\coth_{pq}\left(\sqrt{-\frac{c}{8}}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right)\right)\times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},\tag{35}$$

$$n^{\pm}_{1,9}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\times\left(\pm\sqrt{-\frac{c}{8}}\left(\tanh_{pq}\left(\sqrt{-\frac{c}{8}}\left(\gamma x+\frac{\beta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right.\right.$$
$$\left.\left.+\coth_{pq}\left(\sqrt{-\frac{c}{8}}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right)\right).\tag{36}$$

Case 4: When $c>0$ and $\varepsilon=\frac{a^2}{4}$, then

$$E^{\pm}_{1,10}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\times\left(\pm\sqrt{\frac{c}{2}}\tan_{pq}\left(\sqrt{\frac{c}{2}}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right)\times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},\tag{37}$$

$$n^{\pm}_{1,10}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\times\left(\pm\sqrt{\frac{c}{2}}\tan_{pq}\left(\sqrt{\frac{c}{2}}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right),\tag{38}$$

$$E^{\pm}_{1,11}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\times\left(\pm\sqrt{\frac{c}{2}}\cot_{pq}\left(\sqrt{\frac{c}{2}}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right)\times e^{\iota\left(kx+\frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},\tag{39}$$

$$n^{\pm}_{1,11}(x,t)=\frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}}\times\left(\pm\sqrt{\frac{c}{2}}\cot_{pq}\left(\sqrt{\frac{c}{2}}\left(\gamma x+\frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)\right)\right),\tag{40}$$

$$
\begin{aligned}
E^{\pm}_{1,12}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \Bigg(\pm\sqrt{\frac{c}{2}}\Bigg(\tan_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\beta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg) \\
\pm \sqrt{pq}\,\sec_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg) \times e^{\iota\left(kx + \frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},
\end{aligned}
\tag{41}
$$

$$
\begin{aligned}
n^{\pm}_{1,12}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \Bigg(\pm\sqrt{\frac{c}{2}}\Bigg(\tan_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha r)}\Bigg)\Bigg)\Bigg) \\
\pm \sqrt{pq}\,\sec_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg),
\end{aligned}
\tag{42}
$$

$$
\begin{aligned}
E^{\pm}_{1,13}(y,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \Bigg(\pm\sqrt{\frac{a}{c}}\Bigg(\cot_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg) \\
\pm \sqrt{pq}\,\csc_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha r)}\Bigg)\Bigg)\Bigg) \times e^{\iota\left(kx + \frac{\delta(1-\alpha)t^{-s}}{B(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},
\end{aligned}
\tag{43}
$$

$$
\begin{aligned}
n^{\pm}_{1,13}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \Bigg(\pm\sqrt{\frac{c}{2}}\Bigg(\cot_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg) \\
\pm \sqrt{pq}\,\csc_{pq}\Bigg(\sqrt{2c}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg),
\end{aligned}
\tag{44}
$$

$$
\begin{aligned}
E^{\pm}_{1,14}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \Bigg(\pm\sqrt{\frac{c}{8}}\Bigg(\tan_{pq}\Bigg(\sqrt{\frac{c}{8}}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg) \\
+ \cot_{pq}\Bigg(\sqrt{\frac{c}{8}}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg) \times e^{\iota\left(kx + \frac{\delta(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\right)},
\end{aligned}
\tag{45}
$$

$$
\begin{aligned}
n^{\pm}_{1,14}(x,t) = \frac{\sqrt{-1+k^2}\gamma}{\sqrt{2}} \times \Bigg(\pm\sqrt{\frac{c}{8}}\Bigg(\tan_{pq}\Bigg(\sqrt{\frac{c}{8}}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{s=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg) \\
+ \cot_{pq}\Bigg(\sqrt{\frac{c}{8}}\Bigg(\gamma x + \frac{\tau(1-\alpha)t^{-s}}{C(\alpha)\sum_{r=0}^{\infty}\left(-\frac{\alpha}{1-\alpha}\right)^{s}\Gamma(1-\alpha s)}\Bigg)\Bigg)\Bigg).
\end{aligned}
\tag{46}
$$

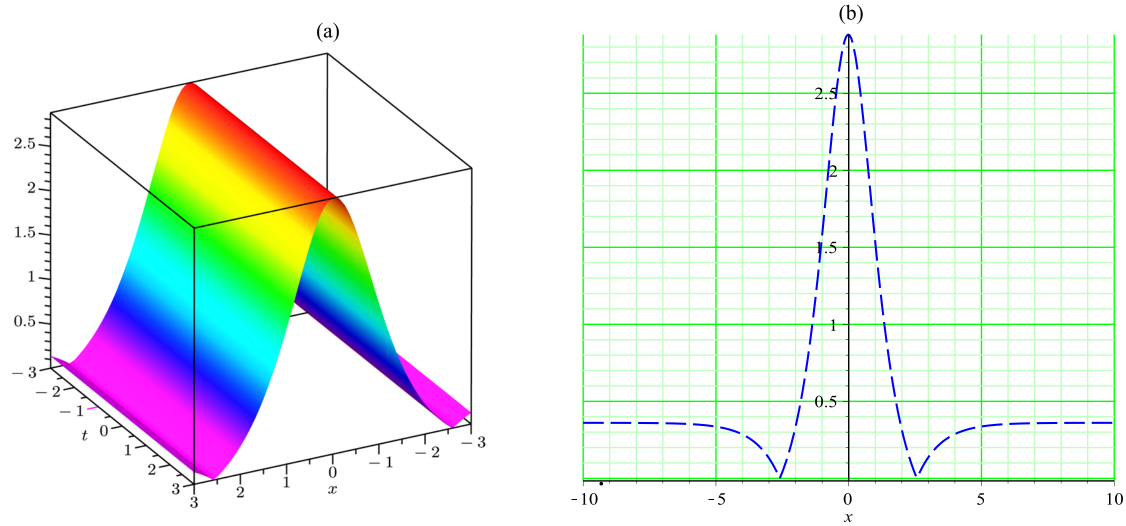

Figure 1: (a) 3D plot of (19) with $k = 0.9, \gamma = 0.87, \beta = 0.3, \varepsilon = 0.4, \alpha = 0.5, B = 0.5, A = 1.76, c = 1.7, p = 0.95, q = 0.98$. (b) 2D plot of (19) with $t = 1$.

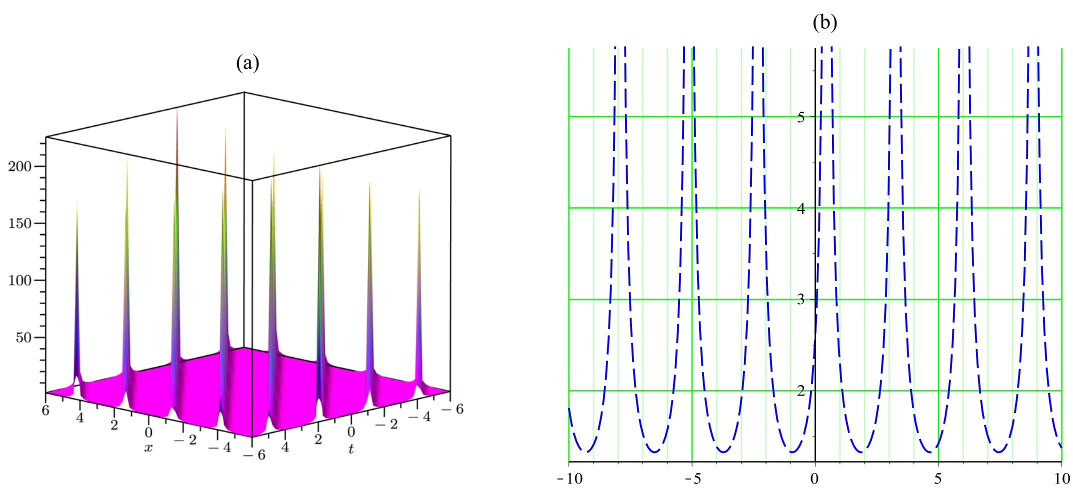

Figure 2: (a) 3D plot of (23) with $k = 0.8, \gamma = 0.85, \beta = 0.2, \varepsilon = 0.5, \alpha = 0.5, B = 0.7, A = 1.75, c = 1.7, p = 0.95, q = 0.98$. (b) 2D plot of (23) with $t = 1$.

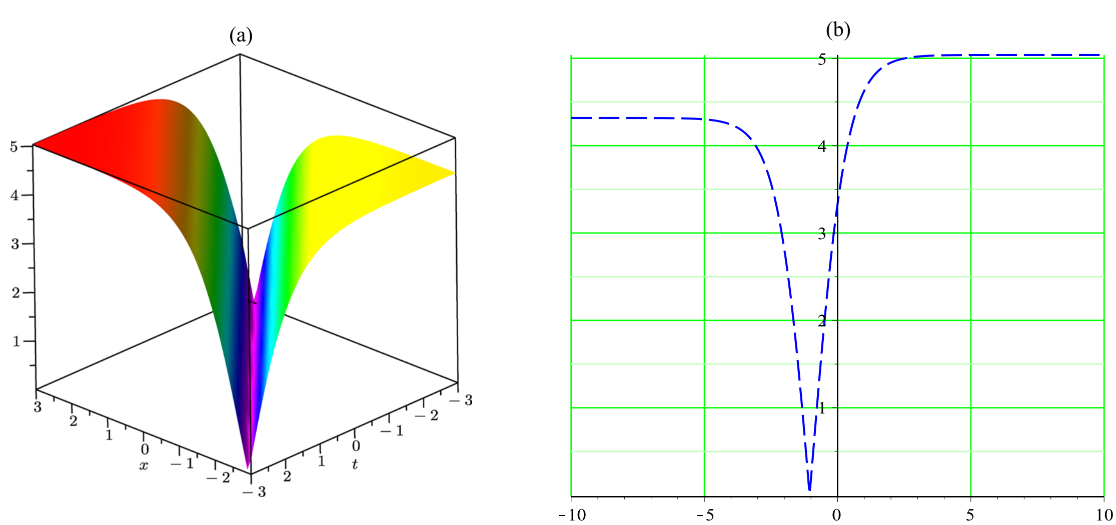

Figure 3: (a) 3D plot of (27) with $k = 0.8, \gamma = 0.79, \beta = 0.1, \varepsilon = 0.6, \alpha = 0.5B = 0.8, A = 1.75, c = 1.8, p = 0.95, q = 0.98$. (b) 2D plot of (27) with $t = 1$.

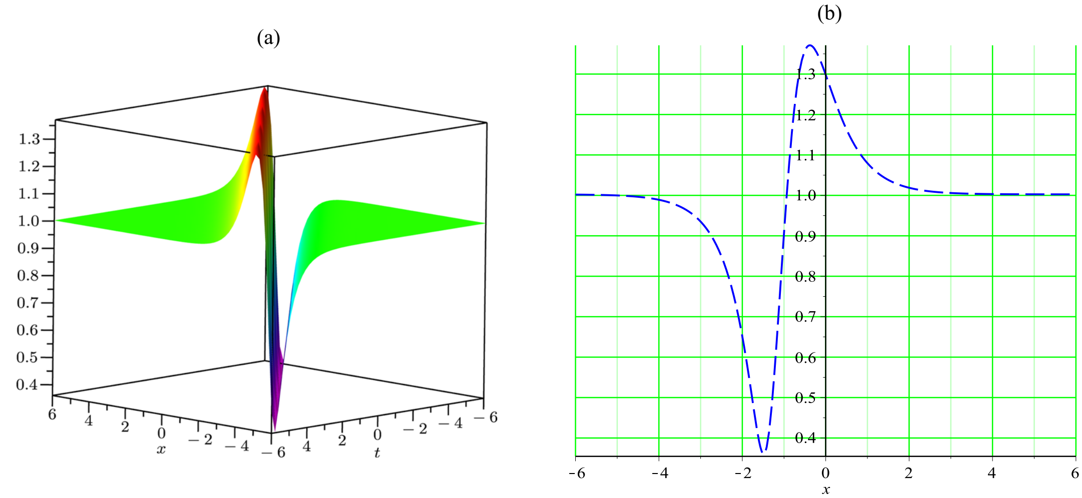

Figure 4: (a) 3D graph of (31) with $k = 0.9$, $\gamma = 0.83$, $\beta = 0.2$, $\varepsilon = 0.4$, $\alpha = 0.5$, $B = 0.6$, $A = 1.75$, $c = 1.4$, $p = 0.95$, $q = 0.98$. (b) 2D plot of (31) with $t = 1$.

4 Results and discussion

The results of this article will be valuable for researchers to study the most noticeable applications for a system of ISALWs with AB fractional derivative. Figures 1–5 clearly reveal the surfaces of the solution acquired for three-dimensional (3D) and two-dimensional (2D) plots, with selection of suitable parameters for the system of equations for ISALWs. Likewise, 3D plots provide us to model and exhibit accurate physical behavior. Through this study, we consider the optical soliton solutions to the nonlinear AB fractional system of equations for ISALWs by using the SSM. The author proposed different analytic approaches in newly issued article and reported some fascinating findings. The author can understand from all the graphs that the SSM is very effectual and more specific in assessing the equation under consideration. In this article, we only added specific figures to avoid overloading the article. For graphical representation of the model under consideration, the physical behavior of (19) using the appropriate values of parameters $k = 0.9$, $\gamma = 0.87$, $\beta = 0.3$, $\varepsilon = 0.4$, $\alpha = 0.5$, $B = 0.5$, $A = 1.76$, $c = 1.7$, $p = 0.95$, $q = 0.98$ and $t = 1$ is shown in Figure 1, the physical behavior of (23) using the appropriate values of parameters $k = 0.8$, $\gamma = 0.85$, $\beta = 0.2$, $\varepsilon = 0.5$, $\alpha = 0.5$, $B = 0.7$, $A = 1.75$, $c = 1.7$, $p = 0.95$, $q = 0.98$ and $t = 1$ is shown in Figure 2, the physical behavior of (27) using the proper values of parameters $k = 0.8$, $\gamma = 0.79$, $\beta = 0.1$,

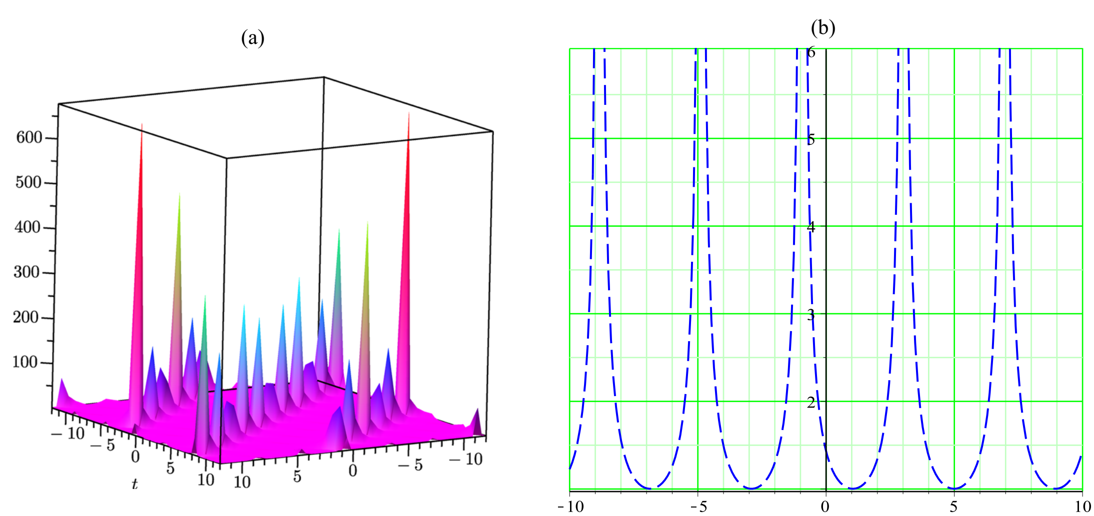

Figure 5: (a) 3D graph of (42) with $k = 0.7$, $\gamma = 0.84$, $\beta = 0.2$, $\varepsilon = 0.6$, $\alpha = 0.5$, $B = 0.7$, $A = 1.74$, $c = 1.7$, $p = 0.95$, $q = 0.98$. (b) 2D plot of (42) with $t = 1$.

$\varepsilon = 0.6$, $\alpha = 0.5$, $B = 0.8$, $A = 1.75$, $c = 1.8$, $p = 0.95$, $q = 0.98$ and $t = 1$ is shown in Figure 3, the absolute behavior of (31) using the proper values of parameters $k = 0.9$, $\gamma = 0.83$, $\beta = 0.2$, $\varepsilon = 0.4$, $\alpha = 0.5$, $B = 0.6$, $A = 1.75$, $c = 1.4$, $p = 0.95$, $q = 0.98$ and $t = 1$ is shown in Figure 4. the physical behavior of (42) using the proper values of parameters $k = 0.7$, $\gamma = 0.84$, $\beta = 0.2$, $\varepsilon = 0.6$, $\alpha = 0.5$, $B = 0.7$, $A = 1.74$, $c = 1.7$, $p = 0.95$, $q = 0.98$ and $t = 1$ is shown in Figure 5. Further, Figures 1 and 2 represent the solutions of (19) and (23) which are bright and periodic singular, respectively. Figures 3 and 4 interpret the solutions of (27) and (31) which are dark and combined dark-bright solitons, respectively. Figure 5 gives the solution of (42) which is combined periodic-singular soliton. Here, the physical structures of the ISALW model are represented under the act of the considered motive force because of the high-frequency field and for Langmuir wave which will support in the study of plasma physics and the influence on rambling structures. These ionic sound waves in plasma are different from the ordinary sound waves in gas.

5 Conclusion

In this article, we have discovered novel soliton solutions as well as trigonometric and hyperbolic functions solutions for the system of ISALWs with AB fractional derivative using the SSM. The obtained solutions are in the form of bright, dark, singular and combo solitons. The bright soliton solutions have a huge advantage in controlling the soliton disorder, and dark solitons are also beneficial for soliton communication when a background wave is existing. Although singular soliton solutions are only elaborated, the shape of solitons shows a total spectrum of soliton solutions created from the model. Furthermore, these novel solutions have many applications in physics and other branches of applied sciences. As far as we know the solutions discovered for under consideration model are fresh and unique. From results, we determine that the SSM is efficient, appropriate and dominant for NLFDEs.

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